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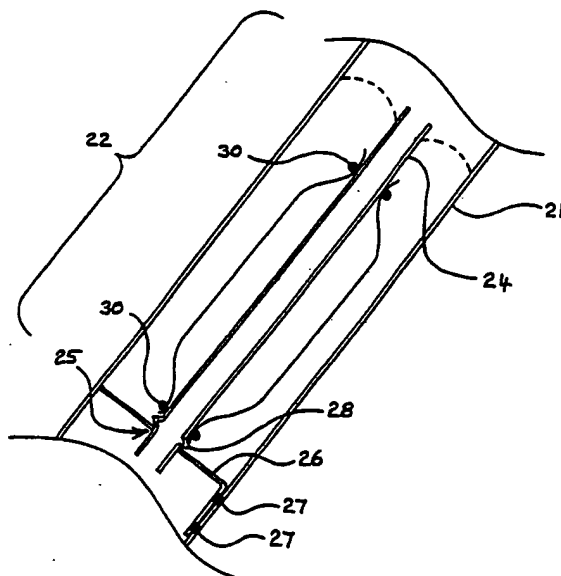
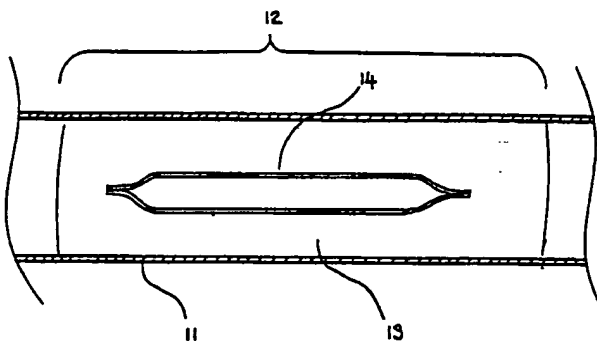
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(57) Abstract

A hollow member (21) is strengthened by inserting a foam precursor means (29) within the member (21) and thereafter heating the structure. The foam precursor means comprises foaming means and plastics material. The heating takes place to a first elevated temperature when the foaming means causes the plastics material, which is then in liquid form, to foam and fill the portion of the hollow member (21) being strengthened, and adhere to the inside walls. The foam so formed is then raised to a higher temperature to cause the foamed plastics material to set. Preferably glass fibre reinforcing is included in the foam precursor means (29). Preferred forms of precursor means (29) include a heat sink (24).

**STRENGTHENING STRUCTURES**

- 5 In the automotive manufacturing industry increasing standards of crash protection for occupants are constantly being demanded by consumers and by legislation. In particular, increased rigidity of the passenger compartment is being demanded. Increased stiffness of the vehicle is also highly desirable to improve handling
- 10 characteristics on the road and reduce vibrations which lead to the development of squeaks and rattles. These goals are difficult to achieve within the constraints of the lighter vehicle masses being required for improved fuel economy and exhaust emissions.
- 15 There is thus a pressing need to strengthen portions of automobiles such as pillars, the anti-intrusion channels in doors and chassis rails without substantially increasing vehicular weight. Substantial experimentation has now resulted in a manufacturing technique that achieves the above aims.
- 20 Accordingly, in one aspect the present invention can be seen as a method of strengthening portion of a hollow member comprising inserting foam precursor means within the member, said foam precursor means comprising foaming means and plastics material, and thereafter heating the structure containing the foam precursor means to a first elevated temperature whereby said foaming means causes the
- 25 plastics material, which is in liquid form at said first elevated temperature, to foam and fill said portion of the hollow member and adhere to the inside walls of the hollow member, and thereafter heating the foam so formed to a second elevated temperature higher than the first elevated temperature to cause the foamed plastics material to set such that when cooled to ambient temperature, and optionally allowed an additional
- 30 curing period, said portion of the hollow member is filled with a rigid foam strongly adherent to the inside walls of the hollow member and providing a strengthening therefor.
- 35 Preferably the foam precursor means comprises a mixture including fibre reinforcing mixed with the plastics material in such a manner that it becomes substantially evenly distributed as a reinforcement within the foam. Preferably such fibre reinforcing is glass fibres although alternatives such as Kevlar aramid fibres, carbon fibres or boron fibres may be used. A mixture of fibre types can be used. Preferably the fibres are in the form of relatively short chopped fibres rather than in long filamentary form, and

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have a length in the order of 2-10mm. The use of fibre reinforcement substantially improves the structural integrity of the final foam product.

- 5 Preferably the plastics material comprises a single-part latent cure epoxy resin which is activated at a temperature higher than the first elevated temperature (where the foaming means activates) but no higher than said second elevated temperature.

- 10 The elevated temperatures required for production of the foam may be produced by the heat treatment of a car body during the painting operations. Preferably this is in the baking oven immediately after the electrocoat application used on most modern vehicles. In conventional modern auto finishing the body is given a total dip electrocoat followed by about 30 minutes in a baking oven where the body is raised to about 175°C. However if there is a delay in the paint line, such that the body stops in the oven, it may reach up to about 250°C. Tolerance of such an elevated temperature  
15 can be provided for by use of an appropriate formulation.

- 20 Preferably a thermal conductor is added to the mixture of the foam precursor means. This may be for example finely divided zinc such as zinc dust or aluminium powder or iron powder. The main purpose of such an additive is to provide improved thermal conductivity in the foam precursor means to allow it to completely heat to the required temperature for foaming and curing during the limited heating time available and also to provide for sufficient heat transfer out of the foam when substantial heat may be produced within it from exothermic reactions involved in the foaming and curing. The use of zinc in the foam may also provide a measure of galvanic protection against  
25 corrosion of steel substrate surfaces.

- 30 Preferably the cured foam produced is a closed cell foam. This provides for improved corrosion protection of the metal surfaces to which it adheres and also provides a positive barrier to vapour and sound transmission along the interior of the member being strengthened.

In another aspect the present invention provides a foam precursor cartridge comprising an outer casing having a melting temperature and containing a foam precursor mixture, said foam precursor mixture comprising:

- 35
- a foaming means which evolves gas at a first elevated temperature above said melting temperature,
  - an activating means which activates at a second elevated temperature higher than said first elevated temperature, and

- a plastics material, which is in liquid form at said first elevated temperature, and can be foamed by said evolving gas at said first elevated temperature, and can be set by said activating means at said second elevated temperature.

5

In a further aspect the invention can be seen as a method of strengthening portion of a hollow member by use of a cartridge as described.

10

One embodiment of the invention will now be described by way of an example of putting the invention into practice.

A foam precursor mixture is prepared by mixing the following components readily available in Australia from the suppliers/manufacturers indicated. The composition is indicated in parts by weight.

15

100 parts bisphenol A epoxy resin (DER 331 from Dow Chemical Co, having an equivalent epoxy weight of 182-190 and a viscosity of 11000-14000 cps);

20

50 parts glass reinforcement (3.2mm long milled glass fibre from Owens Corning Fibreglass);

20 parts zinc dust (microfine grade as supplied by Challenge Metals);

25

6 parts dicyandiamide (DICY MF grade from Anchor Chemicals Australia Pty Ltd);

0.75 parts Imidazole (CUREZOL [trade mark] 2MZ-AZINE grade from Anchor Chemicals Australia Pty Ltd);

30

5 parts aluminium powder (200 grade from Harcross Chemicals);

3.5 parts fume silica (AEROSIL [trade mark] R202, hydrophobic);

35

3 parts UNICELL-OH foaming agent (benzene sulfonyl hydrazide) from Dong Jin Chemical Industries Co Ltd;

3 parts Unipaste (PII) urea activator from Dong Jin Chemical Industries Co Ltd.

The above components are mixed and the resultant mixture is inserted into sausage-like polythene (polyethylene) bags and sealed to form a foam precursor cartridge. The cartridges are sized to conveniently fit within the vehicles' structural members being reinforced. They can be placed into position prior to fabrication of the hollow member  
5 (such as within an open channel prior to its welding to a door to form a side anti-intrusion rail) or can be slid into position after fabrication (such as in the side pillars prior to closing the pillars' end opening).

When introduced into the electrocoat baking oven, the cartridge is heated, and when it  
10 reaches the melting point of the polythene (approximately 130°C), the plastic bag melts and the mixture therein escapes into the hollow member. Care needs to be taken with the placement of holes in the member to ensure that the mixture does not thereby run from its intended region of use. When the mixture reaches the activation temperature of the foaming agent (in this present case the Unicell-OH is activated at  
15 150°C) the foaming agent evolves gas which causes the mixture to foam and expand and contact the inside walls of the hollow member. The use of the epoxy resin in the mixture ensures that it obtains intimate contact and adhesion with the walls even if they are oily from earlier processing or storage. As the oven continues to heat the member, the activator reaches its activation temperature (180°C for the DICY MF)  
20 when it decomposes, the products of which in turn activate the cure mechanism of the epoxy which cures (polymerises) and the foam solidifies in a closed cell form.

The first and second elevated temperatures need to be sufficiently spaced so that both foaming and curing do not happen together. The 20°C separation in the above  
25 example has been found to be appropriate.

Although the above formulation of mixture has been found to be particularly efficient and cost effective in reinforcing automobile pillars and the like, it could be varied if required for particular applications. For example 25 parts of 6mm chopped strand  
30 Kevlar aramid fibres could replace the 50 parts glass fibres for improved performance albeit at an increased cost. Such a material could have anti-ballistic and other armouring applications.

Also the resultant foam could be toughened by adding an elastomer such as 10-40  
35 parts of a carboxylated nitrile rubber (CBTN) to the foam precursor mixture. More preferably though, this would be achieved by adding a toughener such as a difunctional polyoxypropylene with a molecular weight of about 2000, for example Jeffamine D-2000 from Texaco Chemical Co. For this 10-40 parts of the Jeffamine is

pre-reacted with the resin at 100°C in an inert atmosphere prior to their mixing with the other components in the foam precursor mixture.

5 Glass spheres (micro-balloons) can be added to the mixture to lower the density of the final foam and achieve weight savings. The density of the foam could thus be lowered from about 1.3 to about 0.4, although 0.6 to 0.7 is considered optimal.

Although the above described embodiments have a liquid mixture held in polythene bags or pumped into position, suitable formulations can be made which are in solid  
10 form at ambient temperatures and could be introduced into the required position as a solid rod or bar.

In the course of substantial experimentation, it has been found that in some applications the foam produced can in parts reach undesirably high temperatures and  
15 even suffer some thermal degradation due to the heat liberated in the exothermic reaction, even when a thermal conductor component such as metal powder is added as described above to the mixture. Such high temperatures appear to be confined to particularly thick cross sections of foam wherein the thermal conduction path is relatively long for removal of the heat of reaction. For such applications it has been  
20 found that a heat sink means may be advantageously positioned generally central of the cross section such that it is substantially surrounded by the foam prone to high temperature elevation. Preferred forms of such a heat sink and their application will now be described with reference to Figures 1 & 2 attached hereto.

25 Figure 1 is a diagrammatic cross section through portion of a hollow member, such as an automobile B-pillar subject to strengthening in accordance with one embodiment of the present invention. Figure 2 is a diagrammatic cross section through portion of an automobile A-pillar subject to strengthening in accordance with another embodiment of the present invention. In Figure 1 the foam is shown in its expanded state whereas in  
30 Figure 2 the foam precursor cartridge is shown before its activation and the surface of the foam after activation is shown by a dashed line.

Referring to Figure 1, the B-pillar 11 is of box section and is reinforced over portion 12  
35 of its length with foam 13 produced from a precursor mixture described in a following portion of this specification. Held centrally within the foam is the heat sink 14 formed from a length of light gauge steel tubing flattened at its ends to form a substantially sealed container. The heat sink is packaged with the foam precursor mixture and is held in position by wire or lug(s) (not shown) during the foaming process. The heat sink 14 does not fill with foam but provides a sink central of the body of foam into

- which heat can pass during the reaction exotherm, in order to lower the temperature which would otherwise be achieved in the centre of the body of foam. The heat sink size and material of construction may be chosen such that its mass is lower than that of the equivalent volume of foam it displaces, so contributing to a lower vehicular mass. Instead of the form shown in Figure 1, the heat sink could for example comprise a length of metal bar or a preformed slug of thermosetting or thermoplastic resin. The volume occupied by the heat sink allows for the use of less foam, the components of which are a relatively high cost item, so providing a cost saving.
- Referring to Figure 2, the A-pillar 21 is of box section and is to be reinforced over portion 22 of its length with foam of the general type as for Figure 1. The heat sink 24 is formed from a length of light gauge steel tubing open at each end. It locates into a neatly fitting hole 25 in a bracket 26 spot welded at 27 to the inside of the pillar 21. A collar 28 formed on the tubing serves to limit its penetration in the hole 25 and also supports its location substantially central of the pillar 21. The foam precursor mixture is contained within a tubular polyethylene film envelope 29 through which the heat sink passes. The envelope is sealed at its ends against the heat sink by elastic rubber bands 30 to retain the precursor mixture in place between the heat sink and the envelope. The bracket 26 substantially neatly fits the inside cross section of the pillar 21 in order to minimise the loss of any foam precursor components down the pillar.

A particular advantage of the configuration shown in Figure 2 is that there is a continuous duct down the pillar so allowing the convenient routing of electric wiring, or drain tubing from a sunroof, in the vehicle. It is of course not limited to application in vehicle A-pillars, but can be used in other pillars and in non automotive applications.

A further formulation of the foam precursor mixture, particularly applicable to use with the forms of the invention described with reference to Figures 1 & 2, will now be described. The mixture is prepared by mixing the following components readily available in Australia, again from the suppliers or manufacturers indicated. The composition is indicated in parts by weight.

100 parts bisphenol A epoxy resin (DER 351 from Dow Chemical Co), pre-reacted with 10 parts Jeffamine D-2000 from Texaco Chemical Co at 100°C in an inert atmosphere;

10 parts glass reinforcement (6mm long chopped strand from ACI Fibreglass);

6 parts dicyandiamide (DICY MF grade from Anchor Chemicals Australia Pty Ltd);

5 0.5 parts Imidazole (CUREZOL 2MZ-AZINE grade from Anchor Chemicals Australia Pty Ltd);

50 parts aluminium powder (200 grade from Harcross Chemicals);

10 3 parts CELOGEN OT foaming agent from Uniroyal Chemicals;

3 parts plastic microspheres (Expancel 551DE grade of 40-60 micrometres average diameter from International Sales and Marketing Pty Ltd);

15 3 parts Unipaste (PII) urea activator from Dong Jin Chemical Industries Co Ltd.

The above components are mixed and the resultant mixture is packaged using polythene film as previously described to form a foam precursor cartridge.

20 Although the invention has been described with particular reference to the manufacture of automobiles, it will be appreciated that it is similarly adapted to the manufacture of buses and other heavy road vehicles, trains, aircraft, caravans and the like. It also has application in marine superstructures and, with the use of kevlar fibres, could be useful in military applications.

25 Also although the preferred embodiments described above utilised the electrocoat oven to produce and cure the foam, the invention envisages the mixture being inserted, possibly by pumping, into the required positions in the body while it is between the electrocoat oven and the primer application so that it is the primer bake oven that foams and cures the mixture. Similarly it could be inserted between the  
30 primer bake and the top coat application.

Although initially developed for strengthening steel structures, the invention is also applicable to hollow structures of other metals or of plastics or composite materials. An example of such further use is for aluminium window frames required to provide a  
35 significant structural strengthening role. It is common for such frames to be made from a hollow aluminium extrusion and this is often reinforced on the inside with hot dip galvanised steel sections fastened into place. The powder coated paint finish commonly used on these frames requires the hollow aluminium extrusions to be heated to about 220°C, and this provides a good opportunity to deposit a



strengthening foam according to the invention inside the aluminium sections at the same time as the powder coating is being affixed.

5 It can thus be seen that many modifications may be made to the preferred embodiments described above without departing from the spirit and scope of the invention.

**CLAIMS**

1. A method of strengthening portion of a hollow member comprising inserting  
foam precursor means within the member, said foam precursor means  
comprising foaming means and plastics material, and thereafter heating the  
structure containing the foam precursor means to a first elevated temperature  
whereby said foaming means causes the plastics material, which is in liquid  
form at said first elevated temperature, to foam and fill said portion of the hollow  
member and adhere to the inside walls of the hollow member, and thereafter  
heating the foam so formed to a second elevated temperature higher than the  
first elevated temperature to cause the foamed plastics material to set such that  
when cooled to ambient temperature, and optionally allowed an additional  
curing period, said portion of the hollow member is filled with a rigid foam  
strongly adherent to the inside walls of the hollow member and providing a  
strengthening therefor.
2. A method according to claim 1 wherein the foam precursor means comprises a  
mixture including fibre reinforcing mixed with the plastics material in such a  
manner that it becomes substantially evenly distributed as a reinforcement  
within the rigid foam.
3. A method according to claim 2 wherein the fibre reinforcing comprises glass  
fibres.
4. A method according to claim 2 wherein the fibre reinforcing comprises Kevlar  
aramid fibres, carbon fibres or boron fibres.
5. A method according to any one of claims 2, 3 or 4 wherein the fibres have a  
length of between 2mm and 10mm.
6. A method according to any one of the preceding claims wherein the foam  
precursor means includes finely divided zinc or aluminium powder or iron  
powder in an amount that provides a significant increase in the thermal  
conductivity of the foam.
7. A method according to any one of claims 1 to 5 wherein the foam precursor  
means includes finely divided zinc in an amount to provide galvanic protection  
against corrosion of steel in electrical contact with the rigid foam.

8. A method according to any one of the preceding claims wherein the plastics material comprises a single-part latent cure epoxy resin which is activated at a temperature higher than the first elevated temperature but no higher than said second elevated temperature.
- 5
9. A method according to any one of the preceding claims wherein the hollow member to be strengthened forms part of an automobile body and the elevated temperatures required for production of the foam are produced by heat treatment of the automobile body during painting operations.
- 10
10. A method according to claim 9 wherein the elevated temperatures required for production of the foam are produced in a baking oven immediately after an electrocoat application to the automobile body.
- 15
11. A method according to any one of the preceding claims wherein the rigid foam has a density of between 0.6 and 0.7 gcm<sup>-3</sup>.
12. A method according to any one of the preceding claims wherein the rigid foam is a closed cell foam.
- 20
13. A structure strengthened by use of a method according to any one of the preceding claims.
14. A foam precursor cartridge comprising an outer casing having a melting temperature and containing a foam precursor mixture, said foam precursor mixture comprising:
- 25
- a foaming means which evolves gas at a first elevated temperature above said melting temperature,
  - an activating means which activates at a second elevated temperature higher than said first elevated temperature, and
  - a plastics material, which is in liquid form at said first elevated temperature, and can be foamed by said evolving gas at said first elevated temperature, and can be set by said activating means at said second elevated temperature.
- 30
15. A cartridge according to claim 14 wherein said outer casing is a thin film of material which melts at approximately 130°C.
- 35

16. A cartridge according to claim 14 or 15 wherein said plastics material is an epoxy resin.
- 5 17. A cartridge according to claim 16 wherein said plastics material is a toughened epoxy resin.
18. A cartridge according to any one of claims 14 to 17 having its foam precursor mixture containing reinforcing fibres with a length between 2mm and 10 mm.
- 10 19. A cartridge according to any one of claims 14 to 18 having its foam precursor mixture containing finely divided zinc.
20. A cartridge according to any one of claims 14 to 19 having its foam precursor mixture containing microspheres of glass or plastics material.
- 15 21. A cartridge according to any one of claims 14 to 20 having a heat sink means positioned through its centre.
- 20 22. A cartridge according to claim 21 wherein the foam precursor mixture is contained within a generally tubular film of plastics material through which the heat sink means passes.
23. A cartridge according to claim 21 or 22 wherein the heat sink means is formed from a length of light gauge metal tubing.
- 25 24. A cartridge according to claim 23 wherein the tubing is flattened at its ends to form a substantially sealed container.
- 30 25. A cartridge according to any one of claims 21 to 24 wherein the heat sink means is selected to have a mass less than that of the equivalent volume of foam it displaces.
- 35 26. A method of strengthening portion of a hollow member comprising inserting into the member a foam precursor cartridge according to any one of claims 14 to 25, heating the member containing the foam precursor cartridge to said first elevated temperature whereby said foaming means causes the plastics material to foam and fill said portion of the hollow member and adhere to the inside walls of the hollow member, and thereafter heating the member to the second elevated temperature whereby the activating means activates and

causes the foamed plastics material to set while adhering to the inside walls of the hollow member and providing a strengthening therefor.

27. A method of strengthening portion of a hollow member comprising inserting into the member a foam precursor cartridge according to claim 23 and wherein each end of the heat sink means is open, heating the hollow member containing the foam precursor cartridge to said first elevated temperature whereby said foaming means causes the plastics material to foam and expand in said portion of the member, but not enter into the open ends of the heat sink means, and adhere to the inside walls of the member and the outside walls of the heat sink means, and thereafter heating the member to the second elevated temperature whereby the activating means activates and causes the foamed plastics material to set so strengthening the portion of the member while providing a duct through the heat sink means along the strengthened portion of the member.
28. A structure strengthened by use of a method according to claim 26 or 27.
29. A foam precursor solid at ambient temperatures and comprising a foam precursor mixture containing:
- a foaming means which evolves gas at a first elevated temperature,
  - an activating means which activates at a second elevated temperature higher than said first elevated temperature, and
  - a plastics material, which is in liquid form at said first elevated temperature, and can be foamed by said evolving gas at said first elevated temperature, and set by said activating means at said second elevated temperature.
30. A method of strengthening a hollow member as described in the specification with reference to Figure 1.
31. A method of strengthening a hollow member as described in the specification with reference to Figure 2.

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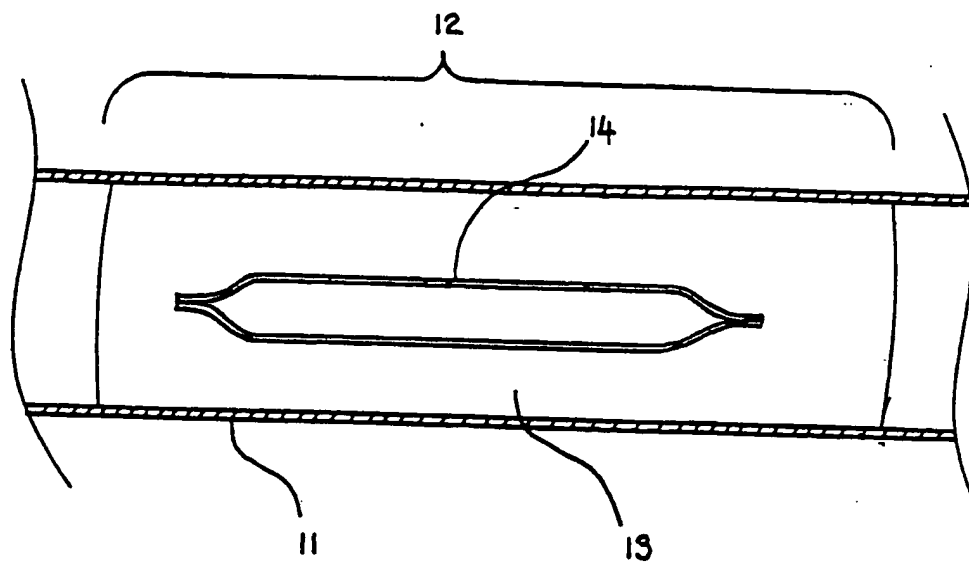


Fig 1.

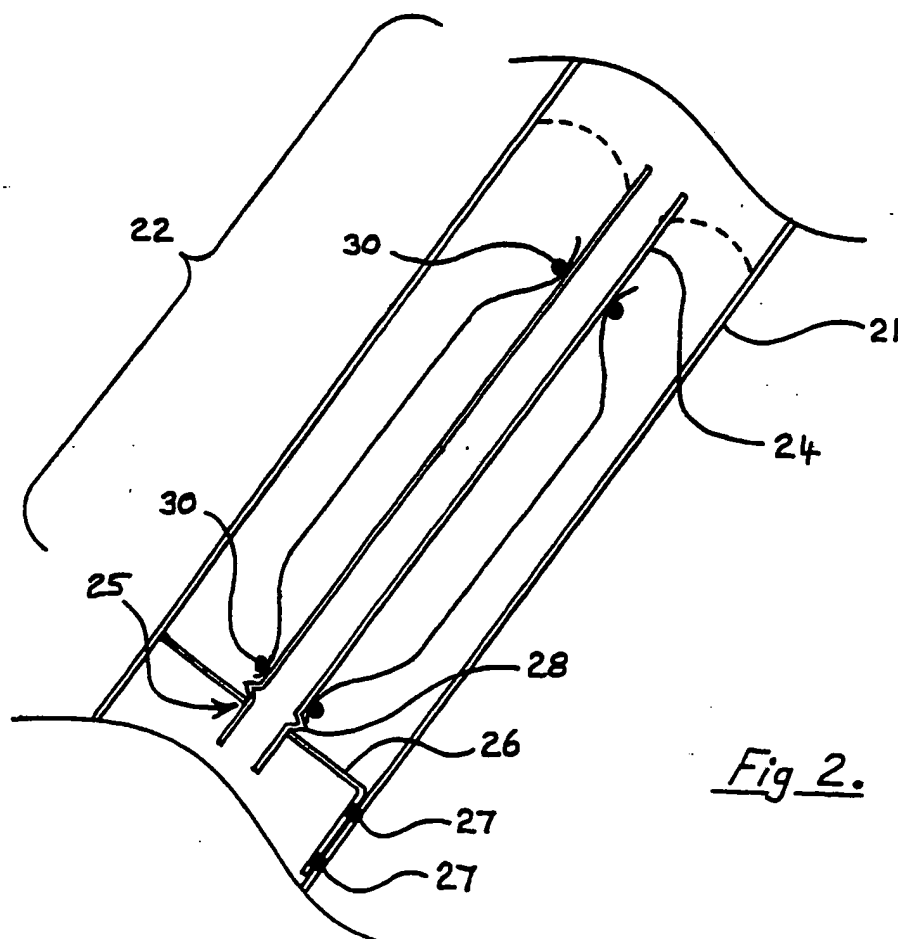


Fig 2.